U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-294 908

Effect of Barite (BaSO4) on Development of Estuarine Communities

(U.S.) Environmental Research Lab, Gulf Breeze, FL

22 Sep 77

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3.
EPA-600/J-78-090	JOURNAL ARTICLE	PB 294908

4. TITLE AND SUBTITLE
EFFECT OF BARITE ($BASO_4$) ON DEVELOPMENT OF ESTUARINE COMMUNITIES

5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Marlin E. Tagatz and Michael Tobia

8. PERFORMING ORGANIZATION REPORT NO.
1EA615

9. PERFORMING ORGANIZATION NAME AND ADDRESS
USEPA
CINCINNATI, OH 45268

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Research Laboratory, Gulf Breeze
Office of Research and Development
U. S. Environmental Protection Agency
Gulf Breeze, FL 32561

13. TYPE OF REPORT AND PERIOD COVERED
final

14. SPONSORING AGENCY CODE
EPA/600/04

15. SUPPLEMENTARY NOTES
Reference: Estuarine and Coastal Marine Science (1978)7,401-407

16. ABSTRACT

Barite ($BaSO_4$), the primary component of oil drilling muds, affected the composition of estuarine communities developed from planktonic larvae in aquaria containing sand and flowing estuarine water. Aquaria contained: sand only; a mixture (by volume) of 1 part barite and 10 parts sand; 1 part barite and 3 parts sand; or sand covered by 0.5 cm of barite. For all environments, annelids and mollusks were the numerically dominant phyla collected in a 1-mm-mesh sieve after 10 weeks exposure; a total of 3020 animals, representing 59 species was collected. Significantly fewer animals and species (α=0.01) developed in aquaria sand covered by barite than in aquaria unexposed or exposed to 1 barite:10 sand. Number of animals in aquaria containing 1 barite:3 sand also differed (α=0.05) from that in control aquaria. Annelids were particularly affected and significantly fewer (α=0.01) were found in all treatments than in the control. Mollusks decreased markedly in number only in barite-covered aquaria. Barite, however, did not impede growth (as height) of the abundant clam, *Laevicardium mortoni*, or decrease abundance of six other phyla. Our data indicate that large quantities of this compound, as discharged in offshore oil drilling, possibly could adversely affect the colonization of benthic animals.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Barite plankgtonic larvae pollution oil toxicity	drilling mud benthic fauna community composition laboratory methods	08/A, 06/F 06/C, 06/T

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
unlimited	unclassified	9
	20. SECURITY CLASS *(This page)*	22. PRICE
	unclassified	PC$4.02/MF$4.01

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDI

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-600/J-78-090
JOURNAL ARTICLE

Reprinted from *Estuarine and Coastal Marine Science* (1978) 7, 401–407

Notes and Discussions

Effect of Barite ($BaSO_4$) on Development of Estuarine Communities*

Marlin E. Tagatz and Michael Tobia

U.S. Environmental Protection Agency, Environmental Research Laboratory, Gulf Breeze, Florida

Received 22 September 1977 and in revised form 15 November 1977

Keywords: drilling mud; pollution/oil; community composition; marine pollution; benthic fauna; laboratory methods

Barite ($BaSO_4$), the primary component of oil drilling muds, affected the composition of estuarine communities developed from planktonic larvae in aquaria containing sand and flowing estuarine water. Aquaria contained: sand only; a mixture (by volume) of 1 part barite and 10 parts sand; 1 part barite and 3 parts sand; or sand covered by 0·5 cm of barite. For all environments, annelids and mollusks were the numerically dominant phyla collected in a 1-mm-mesh sieve after 10 weeks exposure; a total of 3020 animals, representing 59 species, was collected. Significantly fewer animals and species ($\alpha = 0{\cdot}01$) developed in aquaria sand covered by barite than in aquaria unexposed or exposed to 1 barite:10 sand. Number of animals in aquaria containing 1 barite:3 sand also differed ($\alpha = 0{\cdot}05$) from that in control aquaria. Annelids were particularly affected and significantly fewer ($\alpha = 0{\cdot}01$) were found in all treatments than in the control. Mollusks decreased markedly in number only in barite-covered aquaria. Barite, however, did not impede growth (as height) of the abundant clam, *Laevicardium mortoni*, or decrease abundance of six other phyla. Our data indicate that large quantities of this compound, as discharged in offshore oil drilling, possibly could adversely affect the colonization of benthic animals.

Introduction

Barite ($BaSO_4$) is the primary component of muds used in offshore oil well drilling to flush drill cuttings up and out of the bore hole. In processing, mined barite is crushed and ground to serve as an insoluble, dense (specific gravity 4·2) mud-weighting agent.

Drilling mud is discharged as a turbidity plume in the upper layer of water. Although large quantities are recovered and recycled, tons of mud are deposited near a typical Gulf coast well during drilling (George, 1975).

Investigators have found little evidence that barite or drilling-mud is toxic to aquatic organisms. In tests up to 96 h, a concentration of barite drilling mud as high as 7500 parts/10^6 did not kill oysters or various estuarine fishes and crustaceans (Daugherty, 1951). Exposure of oysters (*Crassostrea virginica*) to concentrations of barite between 50 and 65 parts/10^6 for 216 h (Cabrera, 1971) produced no apparent mortality. Grantham and Sloan (1975) reported on the natural occurrence of barium in water, sediment, and all life

*Contribution No. 340, Environmental Research Laboratory, Gulf Breeze.

0302–3524/78/100401+7 $02.00/0

forms; and also showed that sailfin mollies (*Poecilia latipinna*) survived 100 000 parts/10^6 of barite for 96 h. George (1975) found few fouling organisms on test panels suspended in the turbidity plume of drilling mud, photographed the turbid conditions at bottom depths at a platform in the Louisiana Shelf, and suggested that the influence of these plumes on sessile organisms is a physical phenomenon that interferes with feeding and reproduction.

Our study was initiated to determine the effect of barite on development of estuarine communities which result from settling planktonic larvae. The experimental design considered the impact of a barite cover over the substratum as well as a mixture of barite and sediment. A cover of barite could result from the settling of drilling muds; a mixture of barite and sediment, from action of currents and active sedimentation.

Methods and materials

The effect of barite on colonization was determined by comparing numbers and species of animals that grew from planktonic larvae in treated aquaria for 10 weeks (17 August–26 October 1976) with animals in untreated aquaria. Larvae were introduced into the aquaria from flowing unfiltered seawater with its natural component of plankton. We used four apparatuses, described by Hansen (1974), each consisting of 10 adjacent aquaria, 56 cm long, 9 cm wide, and 12 cm high. Aquaria were filled to a depth of 6 cm with either sand (dredged some months previously from Santa Rosa Sound, Florida) or sand and barite.[a] The silica sand consisted of a mixture of 25% coarse particles and 75% medium particles; particle size ranged from 0·2 to 0·7 mm. Only eight inner adjacent aquaria were used in the experimental design; the outermost aquaria contained sand and eliminated any 'end of the row' difference. Water levels were maintained at 9 cm (3 cm above substratum).

The sequence of control and treated aquaria was random among the four apparatuses to eliminate bias due to position. Eight aquaria contained only sand (control), 8 contained a mixture of 1 part barite and 10 parts sand (1:10) by volume, 8 contained 1 part barite and 3 parts sand (1:3), and 8 contained 5·5 cm of sand covered with 0·5 cm of barite (cover).

Seawater with its plankton was pumped from Santa Rosa Sound to an overflow box from which four adjacent siphons supplied water to four constant-head boxes atop the apparatuses at a rate of 2·5 l min^{-1}. Flow to each aquarium was maintained at 200 ml min^{-1} by adjusting the height of a 3·2 mm diameter hole in each of 10 standpipes in the constant-head box. Water flowed from the aquaria through notched end-openings into a common drain. Large predator animals, such as crabs wider than 10 mm, escaped through these openings before their number could drastically affect community structure. Salinity of the water averaged 26·5‰ (22·5–30·0‰); temperature, 25·5 °C (17·0–30·5 °C).

After 10 weeks, animals were collected by siphoning contents of the aquaria into a 1-mm-mesh sieve, preserved and identified. Analysis of variance and Student-Newman-Keuls tests were used to compare numbers and species of animals in control and treated aquaria. All Morton's cockles (*Laevicardium mortoni*) were measured to determine if barite affected growth in height (distance between hinge and distal valve edge).

*E*h profiles of the various sediments, an indicator of the degree of stagnation, were obtained at 6½ and 9½ weeks. Measurements were taken at 1-cm intervals from surface to bottom per aquarium (Cantelmo *et al.*, 1977).

[a] 'Baroid' Division, NL Industries, Inc., Houston, Texas. Mention of commercial products does not constitute endorsement by the U.S. Environmental Protection Agency.

Results

In our harvest at 10 weeks, we collected a variety of animals in all aquaria (3020 animals, representing 59 species of 8 phyla) (Table 1). The three most abundant species were the pelecypod, *Laevicardium mortoni* (983), the tunicate, *Molgula manhattensis* (424), and the polychaete, *Armandia agilis* (280). The numerically dominant phyla were Mollusca, Annelida, and Chordata.

Abundance of animals was affected by barite (Figure 1). Total numbers of animals and species (Table 2) were significantly less ($a = 0.01$) in aquaria sand under the barite cover than in aquaria unexposed or exposed to the 1:10 ratio of barite. Number of animals in aquaria containing 1:3 also differed ($a = 0.05$) from the number in control aquaria; number of species did not significantly differ.

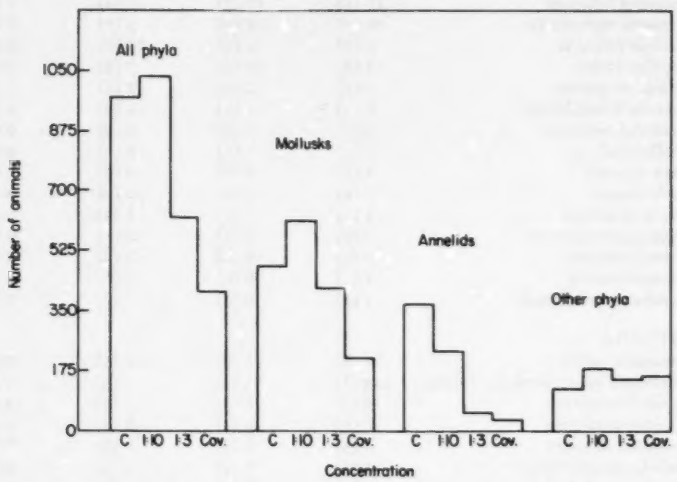

Figure 1. Number of animals, by phylum, collected from control aquaria (c) and aquaria treated with barite (1 barite:10 sand; 1 barite:3 sand; ½-cm cover) for 10 weeks.

Annelids were most affected by barite. Significantly fewer ($a = 0.01$) annelids occurred in aquaria after each treatment than in control aquaria. There was no significant effect on the number of species. However, none or relatively few of the two most abundant species collected, *Armandia agilis* and *Prionospio heterobranchia texana*, occurred in 1:3 or in cover treatments(Table 1).

Abundance of total mollusks was significantly affected only by barite cover, but gastropods were affected by all concentrations of barite. Number of individuals and species of mollusks were fewer ($a = 0.01$) in aquaria sands covered with barite than in control aquaria or in 1:10 treatments. Although the effect of barite on individual species of mollusks varied greatly, the barrel-bubble (*Acteocina canaliculata*) was particularly sensitive. This species, ranked fifth in abundance of all mollusks collected, did not occur in 1:3 and cover treatments. Gastropods generally were more sensitive to barite than pelecypods at all concentrations. Of 168 gastropods (8 species) collected, 58% (7 species) occurred in control aquaria, 21% (5 species) in 1:10, 11% (5 species) in 1:3, and 10% (2 species) in barite cover.

TABLE 1. Animals collected from control aquaria and from aquaria exposed to barite for 10 weeks. (Number of aquaria from which they were collected in parentheses)

Animal	Control	Barite			Total animals
		1:10	1:3	Cover	
MOLLUSCA					
Laevicardium mortoni	268 (8)	364 (8)	219 (8)	114 (8)	983
Anomalocardia auberiana	28 (8)	77 (8)	84 (8)	41 (8)	230
Amygdalum papyria	22 (6)	31 (8)	29 (7)	13 (6)	95
Diastoma varium	37 (8)	15 (8)	10 (4)	8 (5)	70
Acteocina canaliculata	43 (8)	7 (4)	0 (0)	0 (0)	50
Anadara transversa	2 (2)	26 (6)	13 (6)	7 (3)	48
Lyonsia hyalina	14 (8)	15 (6)	9 (7)	3 (3)	41
Cyrtopleura costata	4 (4)	19 (7)	9 (4)	7 (4)	39
Musculus lateralis	11 (5)	17 (7)	7 (4)	2 (2)	37
Triphora nigrocincta	11 (7)	12 (7)	3 (3)	8 (5)	34
Mulinia lateralis	2 (2)	9 (4)	13 (6)	3 (3)	27
Tagelus divisus	2 (2)	10 (5)	7 (5)	3 (2)	22
Tellina alternata	2 (2)	2 (2)	1 (1)	1 (1)	6
Bursatella leachi plei	2 (1)	1 (1)	2 (2)	0 (0)	5
Modiolus demissus	1 (1)	3 (2)	0 (0)	0 (0)	4
Phyllaplysia sp.	1 (1)	1 (1)	2 (2)	0 (0)	4
Abra aequalis	1 (1)	2 (2)	0 (0)	0 (0)	3
Bulla striata	2 (2)	0 (0)	0 (0)	0 (0)	2
Chione latilirata	1 (1)	0 (0)	1 (1)	0 (0)	2
Crassostrea virginica	0 (0)	0 (0)	2 (1)	0 (0)	2
Mitrella lunata	0 (0)	0 (0)	2 (2)	0 (0)	2
Anadara ovalis	1 (1)	0 (0)	0 (0)	0 (0)	1
Haminoea antillarum	1 (1)	0 (0)	0 (0)	0 (0)	1
ANNELIDA					
Armandia agilis	180 (8)	90 (7)	10 (5)	0 (0)	280
Prionospio heterobranchia texana	145 (8)	85 (8)	7 (5)	1 (1)	238
Capitella capitata	19 (7)	8 (5)	5 (3)	4 (4)	36
Hysicomus elegans	0 (0)	9 (5)	8 (5)	9 (6)	26
Neanthes succinea	8 (5)	5 (5)	6 (5)	6 (4)	25
Sabella melanostigma	1 (1)	6 (4)	5 (3)	4 (4)	16
Polydora websteri	0 (0)	8 (3)	3 (2)	4 (3)	15
Dasybranchus lumulatus	6 (5)	3 (2)	0 (0)	0 (0)	9
Eupomatus dianthus	1 (1)	1 (1)	5 (4)	2 (2)	9
Pomatoceros sp.	1 (1)	4 (4)	1 (1)	0 (0)	6
Mediomastus californiensis	0 (0)	2 (1)	0 (0)	1 (1)	3
Neanthes sp.	0 (0)	2 (2)	0 (0)	1 (1)	3
Podarke near *guanica*	1 (1)	2 (2)	0 (0)	0 (0)	3
Polydora sp.	1 (1)	0 (0)	2 (2)	0 (0)	3
Syllis sp.	1 (1)	1 (1)	0 (0)	1 (1)	3
Unidentified Sabellidae	0 (0)	2 (1)	1 (1)	0 (0)	3
Lumbrineris alata	0 (0)	1 (1)	1 (1)	0 (0)	2
Neries pelagica occidentalis	1 (1)	1 (1)	0 (0)	0 (0)	2
Nerine agilis	2 (2)	0 (0)	0 (0)	0 (0)	2
Cistenides gouldii	1 (1)	0 (0)	0 (0)	0 (0)	1
Eupomatus protulicola	0 (0)	1 (1)	0 (0)	0 (0)	1
Notomastus sp.	0 (0)	1 (1)	0 (0)	0 (0)	1
Unidentified Serpulidae	0 (0)	1 (1)	0 (0)	0 (0)	1
CHORDATA					
Molgula manhattensis	77 (8)	122 (6)	114 (8)	111 (8)	424
ARTHROPODA					
Callinectes sapidus	13 (6)	8 (5)	17 (5)	19 (7)	57
Corophium acherusicum	7 (3)	17 (3)	7 (4)	4 (3)	35

TABLE 1—*continued*

Animal	Control	Barite 1:10	Barite 1:3	Barite Cover	Total animals
Eurypanopeus depressus	2 (2)	2 (2)	6 (3)	6 (5)	16
Aneplodactylus sp.	1 (1)	1 (1)	0 (0)	1 (1)	3
Balanus amphitrite niveus	0 (0)	1 (1)	0 (0)	1 (1)	2
Panopeus herbstii	0 (0)	0 (0)	1 (1)	0 (0)	1
Unidentified Paguridae	0 (0)	1 (1)	0 (0)	0 (0)	1
ECHINODERMATA					
Leptosynapta inhaerens	10 (2)	18 (7)	3 (2)	7 (1)	38
Pentamera sp.	1 (1)	0 (0)	1 (1)	1 (1)	3
Lytechinus variegatus	1 (1)	0 (0)	0 (0)	0 (0)	1
COELENTERATA					
Edwardsia sp.	12 (7)	10 (5)	3 (3)	2 (1)	27
Unidentified Actinaria	0 (0)	2 (2)	0 (0)	7 (3)	9
NEMERTEA					
Unidentified Nemertea	0 (0)	5 (2)	0 (0)	0 (0)	5
SIPUNCULOIDEA					
Unidentified Sipunculoidea	0 (0)	0 (0)	1 (1)	1 (1)	2

TABLE 2. Animals and species, by phylum, collected from control aquaria and aquaria exposed to barite for 10 weeks

Phylum	Control		Barite 1:10		Barite 1:3		Barite cover	
	No.	Sp.	No.	Sp.	No.	Sp.	No.	Sp.
Mollusca	474	21	611	17	413	17	210**	12**
Annelida	368	14	233**	18	54**	11	33**	10
Chordata	77	1	122	1	114	1	111	1
Arthropoda	23	4	30	6	31	4	31	5
Echinodermata	12	3	18	1	4	2	8	2
Coelenterata	12	1	12	2	3	1	9	2
Nemertea	0	0	5	1	0	0	0	0
Sipunculoidea	0	0	0	0	1	1	1	1
Total	966	44	1031	46	620*	37	403**	33**

**Significantly less than control at 1% level; * at 5% level.

Growth in height of *Laevicardium mortoni*, which ranged from 1 to 18 mm, was not impeded by barite. Indeed, average height was greater in treated aquaria (9·7 mm for 1:10, 11·3 mm for 1:3, and 10·1 mm for cover) than in control aquaria (8·5 mm).

Barite did not decrease abundance of chordates (*Molgula manhattensis*) and, except for the anemone, *Edwardsia* sp., had no definite effect on species of arthropods, echinoderms, coelenterates, nemerteans, or sipunculoids. Number and distribution of *Edwardsia* sp. in aquaria consistently decreased with increased concentration.

Community structure changed as a result of barite contamination (Table 3). Mollusks were dominant in control and in all concentrations by number of individuals. However, annelids, second in the control and in the low concentration (1:10), were third (after chordates) in higher concentrations. Mollusca and Annelida were represented by the largest number of species, Mollusca generally dominating.

TABLE 3. Percentage composition of individuals and species (by phylum) collected from control aquaria and aquaria exposed to barite for 10 weeks

	Individuals				Species			
		Barite				Barite		
Phylum	Control	1:10	1:3	Cover	Control	1:10	1:3	Cover
Mollusca	49·1	59·3	66·6	52·1	47·7	37·0	45·9	36·4
Annelida	38·1	22·6	8·7	8·2	31·8	39·1	29·7	30·3
Chordata	8·0	11·8	18·4	27·5	2·3	2·2	2·7	3·0
Arthropoda	2·4	2·9	5·0	7·7	9·1	13·0	10·8	15·1
Echinodermata	1·2	1·7	0·6	2·0	6·8	2·2	5·4	6·1
Coelenterata	1·2	1·2	0·5	2·2	2·3	4·3	2·7	6·1
Nemertea	0	0·5	0	0	0	2·2	0	0
Sipunculoidea	0	0	0·2	0·2	0	0	2·7	3·0

*E*h profiles of the 0 to 2 cm layer exhibited similar patterns among the control and experimental aquaria and decreased with increasing depth. A well oxidized upper 2 cm layer (+241 mV) overlaid a slightly less oxidized 2–6 cm layer (Cantelmo *et al.*, 1977). The pattern of decreasing *E*h with increasing depth is similar to the profile reported for natural sandy substrata elsewhere (Fenchel, 1969; Wieser *et al.*, 1974; Cantelmo, 1977).

Discussion and conclusions

Although it appears to be relatively nontoxic to many aquatic organisms, barite, in large amounts as discharged in offshore drilling, could adversely affect the colonization of various substrata by benthic animals. Polychaete worms, a large marine group important in food webs of many marine animals, are particularly sensitive to barite. A decrease in their numbers obviously would alter the normal community structure of a particular area. To a lesser degree, barite decreased abundance of mollusks, especially gastropods. However, growth in height of bivalves did not appear to be hindered. Barite did not significantly alter numbers of animals from phyla other than Annelida and Mollusca. The experiment also indicated that, at the concentrations used, a barite cover had a greater effect on colonization than did a mixture of barite and sand.

We expected that addition of barite to the substratum would affect relative abundance of macrofauna because of the close relationship that exists between the animal communities and the bottom type they inhabit. Thorson (1957) stated that the association between settling pelagic larvae and bottom type appears to be based upon the physical composition of the soil and its content of organic substances; either factor or a combination of both may determine what set of species settle and grow in a particular locality. In addition, he suggested that larvae of predator species, such as gastropods and crabs, are attracted primarily by suitable sediment rather than bottom food. Each type of substratum is selected by a limited and particular set of larval species that, after settling, must survive competition and predation by many animal groups. Thorson (1966) also pointed out that larvae discriminate between attractive and nonattractive substrata, but metamorphosing larvae may have no time to select a bottom and are forced to settle in undesirable substrata. Therefore, low abundance in our heavily treated aquaria may have been due to settlement and subsequent death of metamorphosed larvae in an unfavorable bottom or to the avoidance of that environment by delaying metamorphosis and leaving the aquaria in the effluent water. Thus,

observed differences in the structure of macrofaunal communities in sand and in barite-contaminated sands were due to differences in the settling of meiofauna with subsequent differences in percentage survival and in community interactions.

Acknowledgements

We thank the following people from the University of West Florida, Pensacola, Florida: Dr Frank Cantelmo for obtaining *E*h profiles of the sand environments, and Dr Jerry Oglesby for statistical assistance. We also thank Dr E. L. Bousfield, National Museum of Natural Sciences, Ottawa, Ontario, for assistance in identification of the Amphipoda.

References

Cabrera, J. 1971 Survival of the oyster *Crassostrea virginica* (Gmelin) in the laboratory under the effects of oil drilling fluids spilled in the Laguna de Tamiahua, Mexico. *Gulf Research Reports* **3,** 197–213.

Cantelmo, F. R. 1977 The ecology of sublittoral meiofauna in a shallow marine embayment. City University of New York. Ph.D. Thesis.

Cantelmo, F. R., Tagatz, M. E. & Rao, K. R. 1977 Effect of barite on meiofauna in a flow-through experimental system. University of West Florida. Manuscript submitted for publication.

Daugherty, F. M., Jr. 1951 Effects of some chemicals used in oil well drilling on marine animals. *Sewage and Industrial Wastes* **23,** 1282–1287.

Fenchel, T. M. 1969 The ecology of marine microbenthos. IV. Structure and function of the benthic ecosystem, its chemical and physical factors and the microfauna communities with special references to the ciliated protozoa. *Ophelia* **6,** 1–182.

George, R. Y. 1975 Potential effects of oil drilling and dumping activities on marine biota. In *Environmental Aspects of Chemical Use in Well-Drilling Operations. Conference Proceedings, May 1975, Houston, Texas. Report* No. EPA-560/1-75-004, U.S. Environmental Protection Agency. pp. 333–355.

Grantham, C. K. & Sloan, J. P. 1975 Toxicity study. Drilling fluid chemicals on aquatic life. In *Environmental Aspects of Chemical Use in Well-Drilling Operations. Conference Proceedings, May 1975, Houston, Texas. Report* No. EPA-560/1-75-004, U.S. Environmental Protection Agency. pp. 103–110.

Hansen, D. J. 1974 Aroclor® 1254: effect on composition of developing estuarine animal communities in the laboratory. *Contributions in Marine Science* **18,** 19–33.

Thorson, G. 1957 Bottom communities (sublittoral or shallow shelf). In *Treatise on Marine Ecology and Paleoecology* (Hedgpeth, J. W., ed.). *The Geological Society of America Memoir* No. 67, Vol. 1, pp. 461–534.

Thorson, G. 1966 Some factors influencing the recruitment and establishment of marine benthic communities. *Netherlands Journal of Sea Research* **3,** 267–293.

Wieser, W., Ott, J., Schiemer, F. & Gnaiger, E. 1974 An ecophysiological study of some meiofauna species inhabiting a sandy beach at Bermuda. *Marine Biology* **26,** 235–248.

Printed in Great Britain by Henry Ling Ltd., at the Dorset Press, Dorchester, Dorset